Boeing Research Project

# ACHIEVING INTEGRATION THROUGH INFORMATION SYSTEMS*

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## Achieving Integration Through Information Systems

One of the current schools of thought in organizational research is that there is no one best way to organize and manage human effort. This is the conclusion resulting from the research of Burns and Stalker (1961), Woodward (1964), Lawrence and Lorsch (1967), Perrow (1967), Thompson (1966), and Harvey (1968). However, one cannot conclude that performance is independent of the organization structure. In combination, the two conclusions lead to questions concerning the conditions under which alternative organization designs are most effective. It is the purpose of this paper to discuss such conditions with particular reference to the choice between alternative authority structures and information systems.

The first section of the paper presents a scheme which permits the identification of different kinds of information and decision processes. The second section relates the kinds of information systems to current thinking concerning contingency theories. The purpose is to identify the design variables and the possible trade-offs among them. The last section describes some empirical studies to illustrate the nature of the design choices.

### A Classification of Information Systems

In order to discuss information systems, a considerable amount of ambiguity needs to be removed from the concept. The work of Carroll (1967) is particularly appropriate for this purpose. He distinguishes types of information and decision processes on the basis of the decision mechanism and the formality, timing, and scope of the information flow. Let us look at each of these attributes individually.

The decision maker in any information system may be a _machine_ or a _man_. Some recent research indicates that superior decision-making can be achieved by a cooperative _man-machine_ interaction (Carroll, 1966, and

Morton, 1967). This allows the machine to work on the algorithmic portion of problem solving and the man to work on the heuristic.

The other distinguishing features apply to the information flows to and from the decision mechanism. The first feature is the formality of the flow. The information may be acquired informally by walking through the plant and transmitting it verbally to decision makers. Alternatively, the information may be recorded formally with automatic instrumentation and transmitted via telephone lines to a computer memory. Until very recently all information at the detailed level was recorded informally.

The other two attributes of information systems are illustrated in figure one. The first attribute is the timing of the information flows. At one extreme, the information concerning the status of operations is reported on a periodic basis. For example, once a week the progress on all jobs in the shop is reported and a new schedule for the next week is created. The distinguishing feature is the fixed interval between successive collections of data and/or the making of decisions. At the other extreme is the continuous recording of data as it occurs. In a formal system such a capability is referred to as "on-line". In figure one the timing is dichotomized into the pure types of periodic and continuous. While the timing is actually a continuum it is dichotomized to permit analysis. Alternative timings of information flow affect the age or currency of the information.

The second attribute shown in figure one is the scope of the accumulation of information flows (data base). The scope, like the timing, is dichotomized into two pure types. If the decision maker has access to information only about his immediate location, his data base is called local. On the other hand, if the decision maker has access to information concerning the state of affairs in all departments, his data base is global. The scope

of the data base available to the decision mechanism affects the ability to make decisions which are consistent with decisions made in other parts of the organization.

The typology shown in figure one distinguishes between some prototypical information and decision systems. Let us illustrate each of them.

Scope

| Timing | local | global |
|---|---|---|
| Periodic | Warehouse Clerk | Linear Programming Schedule |
| On-Line | Job Shop Dispatcher | On-Line, Real-Time |

reduced decay of plans ↓

greater inter-unit consistency →

Figure One. Typology of Information and Decision Systems

The first type is the <u>local periodic</u>. It is illustrated by the warehouse clerk who places orders every Friday. He places orders for those items whose actual stock level is below a pre-set minimum level. Clearly the ordering has a periodic timing. The information used to determine which items to order is local. The clerk will not order an item that is not below its minimum but requires a capacity which will be under-utilized. This information system has the virtues of being simple and cheap.

The second type and a more commonly occurring one is the local, on-line. This type is best illustrated by the job shop dispatcher. He is faced with the decision concerning which one of a number of waiting jobs should be processed next on an available machine. The decision-making differs from the local, periodic in that decisions are made whenever a decision needs to be made. In the job shop context this occurs whenever a machine becomes available or a "hot job" requires interruption of a job being processed. However, the data base available is local. The dispatcher may choose a job which will be interrupted in an hour to accomodate a hot job currently in another department. If he had information on the high priority order, he could have worked in a 45 minute job and eliminated the double set-up on the interrupted job. Thus the local, on-line structure has the virtue of decision-making based on the most current information but has the defect of ignoring interactions with decisions made elsewhere.

The third information and decision system is the global, periodic structure. This is characterized by a linear programming based scheduling system. It would operate by collecting information on the status of all jobs in all work centers. The information would be utilized in a linear programming algorithm which takes into account the interactions of all departments by simultaneously determining schedules for all jobs. The resulting schedule would be the basis for activities for the next two weeks. Then a new schedule would be computed. The advantages and disadvantages of the global, periodic are exactly opposite of those for the local on-line. Full account is taken of the interactions between departments. Therefore the behavior in all departments will be consistent with organizational goals. However, the schedule is subject to a decay process. As unplanned absenteeism, machine breakdown, and quality rejects occur, the assumptions on which the schedule was based become less valid. Thus the global data

base allows decisions which take full account of interactions in work flows but the periodic nature of the process permits schedule decay.

The fourth information and decision system is the global, on-line. However, we shall adopt the more popular label of on-line, real-time. The best example of this structure is the airline reservation systems popularized by American Airlines' SABRE system. These systems operate by recording transactions as they occur (on-line) to provide a continuous update. In addition any time a reservation decision needs to be made, it is made with access to global data. Thus the on-line, real-time structure is perfect in theory. It provides for inter-unit consistency of action and makes decisions with the most up-to-date information at the moment of action.

Although the on-line, real-time structure is perfect from the viewpoint of the information system, it is a very costly structure. Therefore its use must be compared to other alternatives for obtaining effective operations. This trade-off is the subject of the next section.

## Current Theory and Information Systems

The current thinking in organization theory was characterized earlier by the statement that there is no one best way to organize. Likewise, it is suggested that there is no one best information system. It is the purpose of this section to define a simplified form of the organization design problem, to suggest that the information system is one of several organization design variables, and to discuss when the prototype forms are appropriate. The last section relates some empirical evidence to support the argument in this section.

The organization design problem is one of balancing the benefits of specialization against the costs of coordination (March and Simon, 1958).

That is, the greater the degree to which an organization is broken down into specialized subtasks, the more effective is the subtask performance. However, the greater the degree of subtask specialization, the greater is the problem of subtask integration into effective performance of the entire task. The integration problem arises because subunit specialization increases the amount of interdependence among subunits. Not only is the number of subunits increased but the connections between subunits increases also. Every organization must arrive at a strategy for coping with the interdependence by allocating resources for coordination or eliminating it by reducing the level of specialization. Along with these strategies go the prototype information systems.

In order to discuss the conditions under which types of information systems are most appropriate, the conditioning variables need to be identified. The first type is the level of technology and the existence of economies of scale. Both of these variables are related to the degree of process specialization in that increases in the level of technology and economies of scale lead to increases in process specialization. In turn process specialization increases the degree of interdependence between subunitsand therefore the need for global information. The global information being needed to obtain consistency among the interdependent subunit activities

The second variable is the degree to which the basic tasks are stable or predictable. Indeed, the task uncertainty, measured by the number of new products (Lawrence and Lorsch, 1967, Harvey 1968) or rate of market change (Burns and Stalker, 1961), is becoming the most powerful independent variable affecting organization structure and process. It is of interest in information system selection because it is related to decay or obsolescence of schedules and plans. The greater the task uncertainty, the faster the rate of decay. Therefore the greater the task uncertainty, the greater the

need for on-line information recording. Thus the conditioning variables are related to organization structures and to the types of information systems.

It should be noted that there are two kinds of uncertainty that affect the complexity of the total integration task. The type that is considered in this paper is the total amount uncertainty in the organization's task. For example, at the Boeing Co., the organizational unit designing and producing the 747 has a more uncertain task than the unit designing and producinc the 707. The second source of complexity derives from differences in task uncertainty among interdependent subunits. For example, the greater the difference between the uncertainty of the engineering task and uncertainty of the manufacturing task on the 747, the greater the complexity of integratic This complexity is due to the different orientations that grow up around the variation in task uncertainty (Lawrence and Lorsch 1967). These two sources of uncertainty interact to determine the complexity of the integration task. The greater the total amount of uncertainty, the greater is the decision making load. The greater the difference in task uncertainty between subunits, the greater the problem of achieving collaboration on joint problems. While both are significant, this paper considers only the first type.

The conditioning variables can be dichotomized and matched with the typology of information systems. Figure two illustrates the transformed typology. If there is low uncertainty and a low need for process specialization, then a local, periodic structure can be adequate. This type is not very interesting from an organization design view.

If the organization has a low need for specialization and a high level of task uncertainty, the local, on-line structure is appropriate. The on-line timing is related to the task uncertainty which makes pre-planning difficult. However, the level of specialization can be reduced by departmentalizing on a product or geographic basis rather than a functional basis. Therefore

a local data base provides sufficient information for consistent decisions. The integration of activities is achieved by removing interdependence and creating self-contained units. Under these circumstances reduced specialization is cheaper than a global information system. The point is also made that the choice of an information system must be consistent with the basis of departmentalization.

| Need For Process Specialization | Task Uncertainty: LOW | Task Uncertainty: HIGH |
| --- | --- | --- |
| Low | Local, Periodic System | Local, on-line Product or Geographic Organizational dept. |
| High | Global, Periodic System | On-line, Real-time or Local, on-line with Buffers |

Figure Two. Typology of Information Systems and Organization Structures.

The third combination is a high need for specialization and a low level of uncertainty. Quite clearly the global, periodic system takes account of the interdependencies caused by specialization. Also the low uncertainty eliminates the decay phenomenon. The global information system is more costly than a local one but it is necessary to achieve the required specialization.

It seems obvious that the case of high need for specialization and high level of uncertainty requires the on-line, real-time information system. This is partially correct. It is only partial because the technology of on-line, real-time information processing is of recent vintage. The procedure used prior to the development of the technology was to use buffers of accumulated orders and inventories to reduce interdependence and rely on local, on-line or global, periodic structures. The cost of this alternative was long delivery lead times for customers and large investments of working capital in inventory. These costs were judged to be smaller than those associated with schedule decay or reduced specialization.

Now they need to be balanced against the costs of on-line, real-time computer systems.

This section has discussed the interaction between information systems, buffers, and the basis of departmentalization in the organization design problem. The independent conditioning variables were the level of technology, economies of scale, and the level of task uncertainty. Let us turn to some empirical work concerning the fourth case of high need for specialization and high level of uncertainty. The studies illustrate the design choices among bases of departmentalization, information systems, and buffers.

## Empirical Studies of Information Systems

The empirical work on management information systems is quite small. However, several recent works can be cited. They all pertain to the most difficult organization design problem. They involve organizations with a high level of technology and a high level of task uncertainty.

The first study is a comparative study of multi-specialist medical clinics (Rockart, 1968). The clinics allow patients to see a number of specialists rather than a single general practitioner. A typical clinic might have five to six specialists in each of ten to twelve departments. There is usually three or four laboratories and X-ray facilities. Since the facilities, both doctors and equipment, are expensive, it is important to achieve full utilization of their time. The problem arises because patients must see a number of doctors. The specialization causes interdependence. Another source of problems is that of unpredictability as to which doctors a patient should see and for how long. In order to schedule, a diagnosis is needed before the patient arrives. For returning or referred patients this is the case, but not for new ones. The problem becomes one of trying to schedule doctors to be fully utilized under considerable uncertainty.

Rockart's work concerned designing a scheduling system for one clinic. Before he did this he traveled to several other clinics. These trips became the basis for the comparative study. Our interest will be in two types of clinics.

The first clinic operates on a local, on-line basis. The patients arrive, are examined by a doctor, and are routed to other doctors on the basis of the examination. There is no pre-scheduling. The diagnosis is made and the schedule determined when all the facts are in. However the schedule is based on local information. In order to prevent schedule conflicts and underutilized doctors, this clinic uses the patients as buffers. The situation is analogous to the job shop. Instead of parts flowing through machine centers, patients flow through medical departments. The waiting lines guarantee full utilization of doctors and equipment. The cost is that the patient spends a good deal of his time waiting.

The second clinic has a more difficult problem. It is located in a large metropolitan area. The result is that patients do not like to wait. They have alternative uses of their time. The other clinic was located in a rural setting. Patients go there almost on a vacation. Hotel accommodations are not as expensive. So the second clinic must find a way to keep doctors fully utilized without long delays to patients.

Any solution must accept the level of specialization as given. Since buffers cannot be used, the clinic must either reduce uncertainty or devote more resources to coordination. One clinic is trying the first by sending an elaborate questionnaire to new in-coming patients in order to reveal symptoms, perform a diagnosis, and schedule the appropriate doctors. Success would allow a global, periodic scheduling procedure. The clinic studied by Rockart used a global, periodic structure but without reducing uncertainty. A central, twenty man staff received in-coming phone calls and mail and tried

to schedule the requests on global listings of doctor availability. However, the decav process was significant and doctors averaged fifteen minutes a day of idle time and patients waited thirty minutes per appointment. The decay was caused by patients who failed to show, doctors being called away, changes in doctor assignments, etc. The result was a switch to an on-line, real time system to allow global data to be used in scheduling through multiple doctors without a significant decay process invalidating the schedule. It can now be updated rapidly and rescheduling can take place as needed. This increases costs by about $75,000 a year, but permits specialization.

This illustrates quite clearly the two points of emphasis. First, there is no one best information system. The clinics mentioned above operate identical technologies with different information systems yet both are effective organizations. This leads to the second point that the information system is only one of several organization design variables. In this case the basis of departmentalization is fixed and the task uncertainty, buffers and information system must be combined into a consistent system. The rural clinic is able to operate under high uncertainty and a simple information system by using buffers. A second clinic is attempting to reduce uncertainty to permit a global, periodic information and thereby reduce buffers. This may be done also by operating only from referrals. The third clinic accepted the high uncertainty and is trying to reduce buffers with an on-line, real-time information system. All these combinations are internally consistent and can lead to effective operations.

The second study is a longitudinal case study of the Commercial Airplane Division of the Boeing Co. (Galbraith, 1968). The comparison of information systems is made on a before and after basis.

The task of the organization is characterized by a sequential work flow from product design through process design, materials acquisition,

fabrication, assembly, and testing. These activities were carried out in a functional organization which created interdependence among the sequential activities. The organization is shown in figure three. In introducing the 707 and the 727 there was a good deal of task uncertainty. The strategy for operating a functional organization in the face of task uncertainty was to use schedule slack and operate a local, on-line information system. Gross scheduling was done at the global level to arrive at due dates to' integrate the sequential functions. However the bulk of decision-making was on-line with a local data base subject to the due date constraint.

In 1964 the market for commercial aircraft changed considerably. The marketing problem for the 707 and 727 was to demonstrate the profitability of jet aircraft in commercial markets. After 1964 jet aircraft were acceptable and demand greatly increased. The problem now was to get as many aircraft built and delivered as quickly as possible. The greater the delay the fewer units that would be sold. The result was a reduction in the schedule buffers and less product development effort on the 737 and 747. The net effect was to sustain a high level of task uncertainty and to make the functional organization vulnerable to schedule disruptions.

Boeing was now faced with a design problem. They needed to make their organization and processes consistent with a minimum use of buffers. With a high level of uncertainty and constrained use of buffers, they could change the organizational form or the information system. The organization structure could be changed by departmentalizing around self-contained units such as the tail, wing, and body sections. Instead of one large scheduling problem from design to test, there would be several smaller scheduling problems. This is the type of organization that arises when a substantial portion of the airplane is subcontracted. This structure would permit a local, on-line information system.

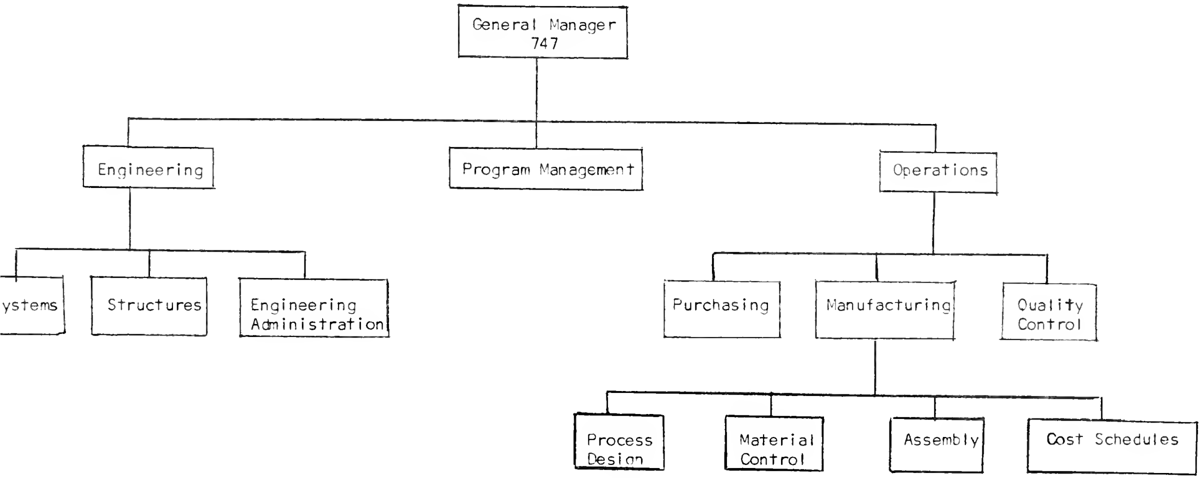


Figure Three. Functional Organization of a Product Branch.

The other alternative is to maintain the same functional organization but substantially increase the resources devoted to processing information. What is needed is a global information system with a frequent updating. This is in fact what happened on the 747 program. A PERT-like scheduling model was used which greatly increased the amount of detailed information available in a central location and increased the capability for handling more information. Thus the price for maintaining a functional organization under high task uncertainty and minimal use of buffers is an expensive information system. However, it is judged that the increased division of labor and manpower utilization afforded by a functional organization more than offsets the expense of the information system.

The Boeing study illustrates an adaptation to an environmental change. It also indicates the tradeoffs between buffers, departmentalization, co-ordination effort, and task uncertainty.

The third study is one currently in progress under the direction of Jay Galbraith and Donald Marquis at MIT. The study concerns 32 R&D projects performed for NASA and the Department of Defense. Thus the contracts required a high level of technology. The state of the art of the projects was sufficiently high to cause a good deal of task uncertainty.

The data from the projects are being analyzed by means of a multiple regression model. The form of the model is shown in equation (1).

$$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5 + b_6 X_6 + b_7 X_7 + b_8 X_8 \quad (1)$$

$$Y = \begin{cases} 1 \text{ if overrun of cost and schedule} \\ 0 \text{ if no overrun} \end{cases}$$

$$X_1 = \begin{cases} 1 \text{ if PERT was not used} \\ 0 \text{ if PERT was used} \end{cases}$$

$$X_2 = \begin{cases} 1 \text{ if there was a large subcontract base} \\ 0 \text{ if small subcontract base} \end{cases}$$

$$X_3 = \begin{cases} 1 \text{ if functional organization was used} \\ 0 \text{ if project organization was used} \end{cases}$$

$$X_4 = X_1 X_2$$

$$X_5 = X_1 X_3$$

$$X_6 = X_2 X_3$$

$$X_7 = X_1 X_2 X_3$$

$$X_8 = \begin{cases} 1 \text{ if negotiated under competitive bid} \\ 0 \text{ if negotiated sole source} \end{cases}$$

The dependent variable, Y, indicates whether or not the project overran its cost and schedule targets. In all cases if a project overran its cost target, it also overran its scheduled due date. Government initiated contract changes which caused overruns on initial estimates were eliminated. The variable was dichotomized. It is equal to one if there was an overrun and zero if there was no overrun or an under run.

The independent variables correspond to the kind of organization design variables that have been discussed previously. The first variable, $X_1$, indicates whether PERT was used on the project. If it was used $X_1$ is zero, if not $X_1$ equals one. If the project did not use PERT, some form of milestone chart or bar chart was used. These categories are assumed to correspond to the global (PERT) and local (n-PERT) classification. PERT is assumed to give a more detailed presentation of schedule status than the other alternatives. There is no data on the frequency of the updating to correspond to the on-line-periodic dimension.

The second variable, $X_2$, indicates the amount of subcontracting activity on the project. It is assumed that the level of subcontracting is related to the size of the coordination task. That is, if a major portion of the effort is performed by subcontractors then the project is more difficult to control than if the project was "in-house". Since it is expected that the relationship is non-linear, the variable was dichotomized at about the halfway point into high ($X_2$=1) and low($X_2$=0) categories.

The third variable, $X_3$, approximates the basis of departmentalization. If a functional organization was used, $X_3$ is equal to one. If a project organization was used, $X_3$ is equal to zero. It is hypothesized that a cost and schedule overrun is more likely to occur in a functional than in a project form of organization. A project was called functional if the professional personnel were physically located in the functional area, if they received merit reviews from the function, and if they received work assignments from a functional manager. If the professional people related to the project manager on all three of the above dimensions, it was classed as a project organization. Fortunately there were no mixed cases.

The next few variables, $X_4$, $X_5$, and $X_6$, are the interaction effects. They represent the tradeoffs that can be made between information systems and departmentalization. It is hypothesized that a functional organization

by itself may not cause an overrun, but a functional organization not using PERT ($X_5=1$) will cause an overrun. Likewise, a project not using PERT may not overrun its targets because it has a project organization. By departmentalizing on a project basis the need for global information is reduced and the project operates adequately with a local, on-line system. Finally, the most likely condition to be associated with an overrun is the second order interaction effect ($X_7$). This means that the project has a high level of subcontracting, a functional organization, and does not use PERT.

The last variable, $X_8$, corresponds to the use of buffers. If the contract for the project is negotiated by competitive bidding, $X_8$ is equal to one. If it was negotiated under a sole source condition, $X_8$ is equal to zero. This assumes that a sole source environment allows the contractor to put some slack into the estimates for costs and schedules.

The results of the regression analysis are presented in equation (2). The t-values are indicated under the respective regression coefficients.

$$\begin{aligned} Y = \underset{(1.27)}{0.35} + \underset{(1.47)}{0.45}\,X_1 + \underset{(0.85)}{0.25}\,X_2 - \underset{(-0.48)}{0.15}\,X_3 - \underset{(-2.50)}{1.25}\,X_4 + \underset{(0.07)}{0.03}\,X_5 - \underset{(-0.55)}{0.25}\,X_6 + \\ \underset{(2.04)}{1.47}\,X_7 + \underset{(1.02)}{0.20}\,X_8 \end{aligned} \tag{2}$$

The most significant variables are $X_4$, $X_7$, $X_1$, and $X_8$. The significance of the variable $X_4$ is somewhat confusing due to its negative sign. This means that cost and schedule performance of a project organization, not using PERT and with a high level of subcontracting is the optimal way to perform a project. There is no obvious explanation for this result.

The other significant variables are in the predicted direction. The second order effect, $X_7$, indicates that the functional organization that does not use PERT and has a high level of subcontracting is most likely to overrun its cost and schedule targets. A functional organization that does use PERT is not likely to overrun its targets. This is consistent with the notion that global information systems are needed with high levels of specialization (functional organization).

The other two significant variables are the independent PERT effect, $X_1$, and the sole source negotiation (buffers), $X_8$. Thus those projects that do not use PERT, independent of the organizational form, and likely to overrun their cost and schedule targets. Likewise those contracts that are negotiated under competitive conditions are more likely to overrun their cost and schedule targets than those contracts negotiated sole source. Actually, the contracting basis should be run as a third order interaction effect. However the increase in the number of variables approaches the number of observations and all variables may not be represented by observations.

The other factor in the design of organizations for large R&D projects is the technical performance of the hardware. Marquis and Straight (1964) have shown that functional organizations perform at a higher technical level than project organizations. This would indicate that the best organization for R&D projects is a functional organization that uses PERT or is able to use schedule slack to act as a buffer. This does not include any of the newer matrix forms now being used.

## Summary

This paper has introduced a way of talking about information systems and has indicated some of the bases on which one can choose an appropriate information system. It was indicated that there is no one best information system but that it depended on the task uncertainty, basis of departmentalization and the ease of using buffers.

It was also indicated that the choice among the organization design variables be internally consistent. For example, a high level of specialization is not consistent with an information system having a local data base unless there is a high level of buffering. The Boeing Study illustrated quite clearly that a change in one of the variables requires a change in the others to maintain the consistency.

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